Thesis Proposal

Park Place Corporate Center One

Findlay Township, PA

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Executive Summary

The following proposal is intended to provide an academic experience and set the stage for future discovery for the spring semester of 2011 for Park Place Corporate Center One (Park Place 1). Park Place 1 was selected to be studied because it is a common building type. That said, the knowledge that can be gained by studying Park Place 1 should translate over to many future projects and designs. The goal of this proposal is to establish a plan to study mechanical systems by studying those of Park Place 1.

Park Place 1 has a simple system currently designed. The system contains two packaged rooftop units that provide conditioned air for both heating and cooling. The systems were selected because of convenience and cost. The opportunity being presented in this proposal is to understand the cost of the designed system and then to expand upon that to understand the effects of changing the system. By effects, the intention is to model the energy consumption of the building, determine the first cost, and establish whether or not the life cycle cost of various system types can outweigh the initial cost. To accomplish this task, a usable and accurate energy model needs to represent real design alternatives. The purpose of this study then, is to better understand the difference between the proposed systems.

The alternates being studied are first the designed system, second replacing that system with a chilled water system, and third to add thermal storage to the second system. The reason that chilled water has been selected is to determine the difference between using a packaged DX system and a non-packaged chilled water system. The intention then is to take that one step further and find out if adding thermal storage improves the chilled water system enough to justify the initial cost. At that point, all three systems can be compared economically and by performance to determine which system is the best to install.

This report also proposes the needs associated with installing the design alternatives. Part of the appeal to using rooftop units is that they are space efficient and do not have many special requirements. The proposed systems are more complicated and also require more equipment. That equipment has weight and requires physical space. To study the feasibility, the structure of the roof or the potential addition of such equipment to the site need to be studied.

The conclusion of this report presents a schedule of work to be accomplished throughout the spring semester of 2011.

Mechanical Summary

Introduction

Park Place 1 has a central building mechanical system that serves 100% of the building to satisfy all heating, cooling, ventilation, and exhaust requirements. The building spaces are currently served by variable air volume (VAV) valves that allow for full mechanical modulation during part load occupancy. The base supply duct system is intended to suit future expansion with the assumption of VAV terminal boxes being used to supply air to individual spaces. Air will be supplied to these boxes through one of two vertical shafts that house both supply and return/exhaust air ducts. Two packaged rooftop air handling units (RTU) equipped with variable speed drives will split the building loads equally. Two existing gas fired boilers will meet the majority of the perimeter heating load by supplying hot water to perimeter duct reheat coils with the RTU's serving as the air handling unit and primary source of heating.

Design Criteria and Objectives

In the design of any system, several factors need to be weighed. The ultimate goal of a mechanical system is to provide air that both legally and practically meets the needs of the building occupants within the boundaries of cost. This is a relationship that involves three major parties: the owner, the occupant, and the government. Each party has needs that need to be addressed in the design process by the engineer. For the engineer to accomplish such a task, he or she must look at each party individually and then weigh the considerations. For the owner, system cost becomes the major focal point. This entails first cost, operating cost, and maintenance cost. For the occupant, air cleanliness, temperature, and humidity are the primary concerns all while maintaining a certain level of ventilation. For the government, compliance with modern codes is mandatory and therefore can be one of the minimum starting points for the design engineer.

The mechanical system of Park Place 1 is intended to meet all of the requirements of ASHRAE Standard 55 – 2004 Thermal Environmental Conditions for Human Occupancy, ASHRAE Standard 62.1 – 2007 Ventilation for Acceptable Indoor Air Quality, and ASHRAE Standard 52.2 which pertains to particle removal from the supply air stream. The new mechanical equipment that was installed during the building renovation was intended to meet the requirements of ASHRAE Standard 90.1 – 2007 Energy Standard for Buildings Except Low-Rise Residential Buildings. For further study on compliance with ASHRAE Standards 62.1 and 90.1, please see Technical Report 1. Such topics address the needs of compliance with government standards.

With respect to building occupancy, Park Place 1 is exclusively an office building. As examples, there are no laboratories requiring very specific air quality conditions, no garages that need special exhaust system considerations, and no gyms that need a very precise temperature set point. To design a successful space, typical office building assumptions in accordance with the ASHRAE standards were made. This implies that occupants would be relatively sedentary and wearing normal clothing, internal loads would be predominantly driven by lighting, people, and receptacle loads, and that construction would be of medium to low quality because of age.

The owner, DiCicco Development, has cost in mind. Park Place 1 is a building that was designed for profit. DiCicco Development wants their occupants to be happy with their experience of renting one of their spaces. With that said, the building owner made it clear to the design team that it was their goal to provide an environmentally responsible building that at the same time satisfied the occupants who would be exposed to the systems. Because of the buildings age and the consideration that the building is to be rented for profit, DiCicco Development wanted to find the best solution that weighed first cost, operating cost, system efficiency, and maintainability. While certain modern systems could potentially have been more viable in the long term, DiCicco Development did not want a system with a lengthy payback period. Their goal was a system with a reasonably low initial cost and a consideration for operating cost. They wanted to find an economic balance. It was also made clear to the design engineer that the personnel in charge of maintenance, while experienced, was not sophisticated enough to handle an extremely complicated system. Also, because the building was not LEED rated previously, it did not become a major priority for the design team.

Outdoor and Indoor Design Conditions

In determining equipment capacity, both outdoor and indoor design conditions must be determined. Indoor design conditions are chosen in accordance with ASHRAE Standard 55 and are subject to personal preference amongst the building occupancy. In other words, not everyone agrees on what is comfortable and therefore a range of temperature control must be provided. Outdoor design conditions are based on TMY2 weather data which is collected over years of recorded weather data and trends. Park Place 1 is located in Findlay Township, Pennsylvania, a suburb of Pittsburgh, Pennsylvania. Because Pittsburgh is the closest major city that has weather data accumulated and documented, it was used as the basis of location for design. Pittsburgh is known for having relatively cold winters and warm, humid summers as seen below in Table 2- Outdoor Design Conditions. The 0.4% and 99.6% design days were chosen to be used for equipment selection for Park Place 1. Together, both outdoor and indoor conditions must be considered to appropriately size mechanical equipment.

Thermostat Settings	
Cooling Dry Bulb (°F)	75
Heating Dry Bulb (°F)	70
Relative Humidity (Cooling Only) (%)	50
Cooling Driftpoint (°F)	81
Heating Driftpoint (°F)	64

Table 1- Indoor Design Conditions

In Table 1 above, the indoor design conditions can be seen. They are the typical set points for an office building. In Table 2 below, the outdoor ambient conditions are shown that were used to size the mechanical system equipment for capacity.

Outdoor Design Conditions		
	Summer (0.4 %)	Winter (99.6 %)
Dry Bulb (°F)	89.1	1.8
Wet Bulb (°F)	72.5	-
Dew Point (°F)	65.6	-
Clearness	0.97	0.97
Ground Reflectance	0.2	0.2
Wind Velocity	11.7	15

Table 2- Outdoor Design Conditions

System Design and Equipment Summaries

Given the design considerations outlined above, the design engineer chose to implement a system as described in the following sections that address air supply and exhaust as well as hot water systems.

Air Supply System

Packaged Rooftop Units

The building air supply is handled entirely but two identical rooftop units (RTU-1, RTU-2) for the heating and cooling seasons.

For cooling, the RTU's are direct transfer (DX) type, meaning the air stream is cooled by a cooling coil that has liquid refrigerant circulating through it. The RTU's have air-cooled condensers with accompanying fans that increase the heat transfer rejection rate to the ambient surroundings to turn the refrigerant from a compressed gas back to a liquid. The compressors are direct drive scroll type with hermetic motors. The supply air temperature from the RTU's can be modulated along with the supply cfm's, but for capacity was sized for a leaving air temperature of 55°F (the desired supply air temperature to the occupied space).

For heating, the RTU's have forced draft gas burners that are capable of providing 85°F air. When speaking with the design engineer, it was determined that the existing gas-fired boilers were capable of handling the entire heating load for the building but that the RTU's would be used as the main heating source following the renovation. During the heating season, the boilers' heating capacity will be used as a redundant back up, the primary purpose being to supply 180°F water to reheat coils around the building perimeter.

RTU-1 and RTU-2 are responsible for cooling air during the summer, warming air during the winter, and also moving air throughout the building during both seasons. There are no other air handling units in the building. To meet the air handling requirement, both RTU's have a supply (airfoil type) and return (forward curved type) fan equipped with variable speed drives that allow for full modulation of supply and return air quantities. The RTU's are also equipped with a 100% outdoor air economizer which allows for each RTU to serve as a dedicated outdoor air system should the opportunity present itself. The economizers, in combination with the unit controls, are also capable of demand control ventilation based on CO_2 measurements taken in the occupied spaces. The RTU's are capable of providing 45,000 cfm's of supply air each. For air quality purposes, MERV 7 prefilters and MERV 13 final filters have been installed into the units to remove potential air contaminants. For safety, the units have been equipped with smoke detectors in both the supply and return ducts that are wired directly to the units' control systems.

Because controls are an ever increasing priority in the HVAC industry, the RTU's have been equipped with microprocessor controls. This system consists of temperature and pressure (thermistor and transducer) sensors and a human interface panel that are capable of tying into the building automation system (BAS) that is included as part of the building renovation.

The RTU's performance characteristics can be seen below in Table 3 – Rooftop Unit Schedule.

Rooftop Unit Schedule			
Name	RTU-1	RTU-2	Units
Air Quantity	45,000	45,000	cfm
Minimum Outdoor Air	4,500	4,500	cfm
Heat Output	1,100,000	1,100,000	Btu/Hr
Gas Input	1,380,000	1,380,000	Btu/Hr
Entering Air Temperature- Heating	63	63	°F
Leaving Air Temperature- Heating	85	85	°F
Cooling Capacity	115	115	Tons
Entering Air Temperature DB- Cooling	77.5	77.5	°F
Entering Air Temperature WB- Cooling	64.3	64.3	°F
Ambient Temperature- Cooling	89.1	89.1	°F

Table 3 – Rooftop Unit Schedule

Distribution

An essential part of any mechanical system is the delivery of air from the air handling unit to the occupied space. In this case, outdoor air and return air mix in the packaged rooftop units' mixing boxes where a portion of that air is exhausted, the rest of be recycled and sent through the system. Once that mixed air is re-filtered and re-conditioned in one of the two RTU's, it is pushed through one of two central shafts that run vertically through the center of the building. From these shafts, main branch ducts at every floor deliver supply air to individual terminal boxes where the air is then supplied to the space. If, in some cases, the run of duct work is over an extended length of duct, hot water duct reheat coils have been installed to increase the supply air temperature during the heating season. This is especially applicable to perimeter spaces. If a future designer desires the use of a fan-coil unit or a reheat coil in a VAV box, the ability to tap off of the main hot water supply line is feasible.

Supply Fans				
Unit	Type	hp	CFM	Service
RTU-1	AHU	75	45000	Whole Building
RTU-2	AHU	75	45000	Whole Building
FPCV-A	Terminal	1/6	200	Office Space
FPCV-B	Terminal	1/6	350	Office Space
FPCV-C	Terminal	1/4	750	Office Space
FPCV-D	Terminal	1/2	1000	Office Space
FPCV-E	Terminal	3/4	1400	Office Space
FPCV-F	Terminal	1	1800	Office Space
FPCV-G	Terminal	1	2300	Office Space
FPVV-A	Terminal	1/6	200	Office Space
FPVV-B	Terminal	1/6	350	Office Space
FPVV-C	Terminal	1/4	750	Office Space
FPVV-D	Terminal	1/2	1000	Office Space
FPVV-E	Terminal	3/4	1400	Office Space
FPVV-F	Terminal	1	1800	Office Space
FPVV-G	Terminal	1	2400	Office Space

Table 4 – Supply Fan Data

Return/Exhaust Fan Compliance				
Unit	Type	hp	CFM	Service
EF-1	Exhaust	1	3500	Restrooms
RTU-1	Return	40	40500	Whole Building
RTU-2	Return	40	40500	Whole Building

Table 5 – Return/Exhaust Fan Data

Terminal Units

Because the building is a tenant fit out, there is a variety of potential system designs that could be implemented in conjunction with the base building mechanical systems. According to the design engineer, VAV boxes, fan-powered boxes, or a number of other terminal units can be used to supply air to individual spaces. In the event that supplemental heat is needed, hot water from the boiler can be made available. It is the intention of the owner and designer however, that the boiler be used as little as possible.

Air Exhaust/Return System

Once the air has passed through the occupied space, it is returned through a pressurized ceiling plenum where it is drawn by a return fan in the RTU's. A certain percentage of that air is exhausted, the remainder to go through the process again. Restroom exhaust is handled by a separate duct that runs through a separate vertical shaft as the supply/return air (one additional shaft for each side of the building). Any additional exhaust requirements, such as kitchen hoods can be connected to the restroom exhaust shafts. 100% of this restroom air is exhausted; none of it is recirculated.

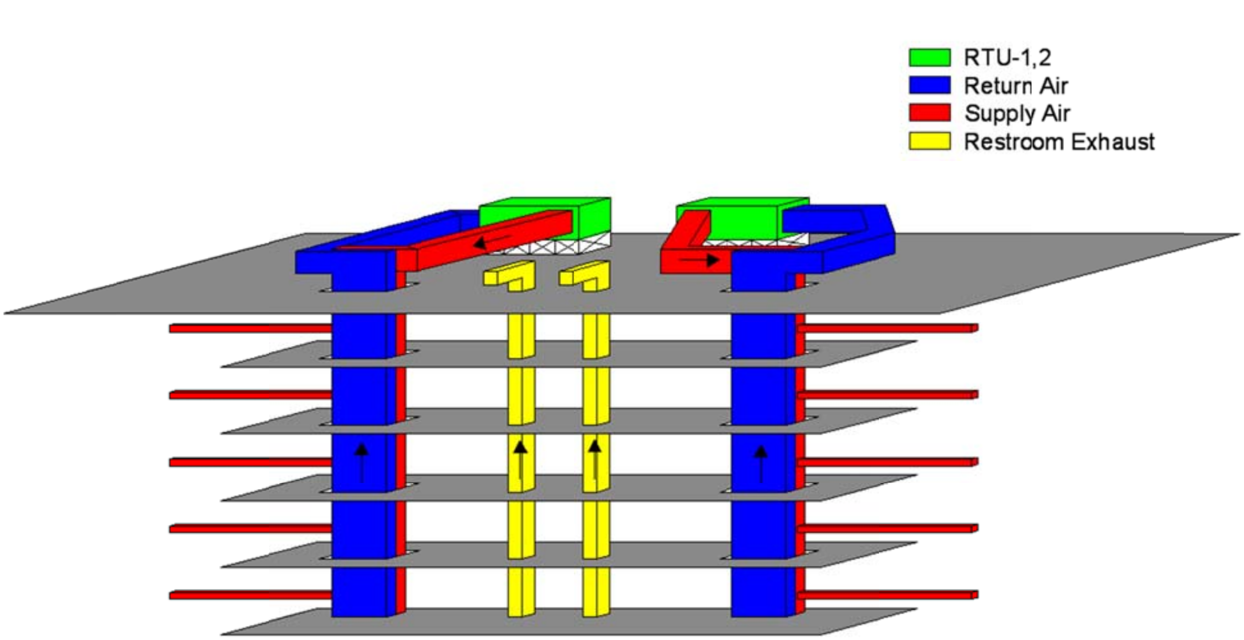


Figure 1 – Air Circulation Schematic

Seen above in Figure 1, the air circulation for Park Place 1 begins and ends on the roof. The RTU's shown in green above, are located just outside of the rooftop penthouse. The supply fresh air through the ducts shown in red to all occupied spaces on floors one through five. The air leaves from the unit, enters into the rooftop penthouse, is pushed down through one of two vertical shafts, and then is distributed through branch ducts to terminal boxes. The blue ducts shown above are similar except that in place of branch ducts, a pressurized ceiling plenum returns air to the RTU's. The two ducts shown in yellow are restroom exhaust shafts that are completely separate of the rest of the mechanical system. These two shafts are powered by to exhaust fans located within the rooftop penthouse.

Hot Water System

The existing gas fired boilers may or may not remain throughout the renovation. The owner has opted to see multiple cost alternatives to keeping the system or not. If they do remain, these boilers will provide 180°F water that will be used for duct reheat coils and heating coils located in future terminal boxes. The water is pumped from the boilers through two inline pumps located adjacent to the boilers. Again, the hot water system is to be used as supplemental heat if at all.

Evaluation of System

When Park Place 1 was originally constructed, it was done so with the intention that an interior air handler would use a split system for cooling and a gas fired boiler for heating. Because the two systems were separate, the controls were complicated and the system did not perform well. This caused inefficiencies and unhappy tenants. When DiCicco Development purchased the building and decided to improve the mechanical systems, they made an excellent choice to consolidate the two systems into one.

While some buildings have a hot/chilled water system, the design engineers saw an opportunity to economically use an air only system. Park Place 1 does have a hot water system but no chilled water system. To combine the two systems into one with a changeover would have been costly and required the further purchase of cooling equipment. The option of using modern rooftop units capable of providing both heating and cooling would eliminate the need for the boiler, pumps, and water system as a whole. Also, because the RTU's are new, they function more efficiently, are more reliable, easier to control, and require one service contract as opposed to several. While they are probably not the most energy efficient or cheapest choice over the life of the equipment, they come with minimal first cost and reliability. When the design considerations were taken into account, modern rooftop units were probably one of the best choices to meet the needs of the owner.

There is still some room for investigation however. Park Place 1 offers many opportunities for systems with higher first cost but lower operating cost. These systems will be proposed throughout the rest of this study.

Proposal

Mechanical System Proposal

The reason that Park Place 1 was chosen for this study is because of the abundance of similar buildings in the United States—a common office building with simple, inefficient energy systems. It allows for the comparison of systems without the variables that would complicate such a study. It is more important to understand the differences in the various mechanical systems than it is to understand various buildings. The reason being that no two buildings are the same, however, there is a finite number of mechanical system types. The purpose of Park Place 1 is to serve as a control with elementary systems and then to investigate the pros and cons of increasing the complexity of the mechanical systems. The current design of the Park Place 1 mechanical systems was intended to be simple to operate, reliable, and reduce first cost. This type of design lends itself to many different areas where improvements can be made. The following will detail three mechanical system alternatives and two breadth studies that will also come into play if the mechanical systems are changed.

The three proposed alternatives are first to model the system as it is, second to change that system to a chilled water system, and third to add ice storage to the second system. In this way, there are three systems with increasing complexity and potential energy savings. In all alternatives, the equipment will be placed on the roof of Park Place 1. This is where the breadth studies are required to determine feasibility. A chiller and ice storage will add significant weight to the building's roof. Because of this, it must be determined if the existing structure of the building is capable of handling such weight and if so, how much. The second breadth proposal will be to determine what the overall reduction in electrical equipment capacity will be for the ice storage system.

Alternative 1 – As Designed

The first mechanical system to be analyzed is the base system that was designed. This alternative will serve as the control from which to evaluate the subsequent design proposals. This design is the one that has been discussed in the previous technical reports. It includes packaged rooftop units that will provide conditioned variable volume air to terminal boxes that serve the occupied spaces.

Alternative 2 – Chilled Water System

The second proposed system will be to replace the rooftop units with a chilled water system and accompanying equipment. This means that a chiller, air handling unit, boiler, pumps, and piping must all be added to the system. The idea being that chilled water would be provided to terminal boxes or an air handling unit, the current design intent, that will condition the space.

The largest associated cost of this system will be in the first cost of the chiller. The selection of the correct chiller is vital to a good design. The first decision to be made is whether the chiller will be air cooled or water cooled. In this case when the cooling load is small, an air cooled chiller will be both cheaper in first cost and will remove the need for a cooling tower. This will come at the sacrifice of efficiency because water cooled chillers tend to be more efficient than air cooled chillers. Second, without a doubt, an electric motor will be selected. This has to do with lowest associated first cost, minimal building disruption, and availability of resource. Another major consideration is the type of compressor to use. Because the building load is relatively small for a chiller/chilled water system, a chiller with a reciprocating or scroll compressor will be selected. In this application, centrifugal compressors are too expensive, especially for such a small load—they become more efficient at higher loads—and screw compressors are generally sized for larger capacities—the low 1000's of tons.

Another major consideration is the type of pumping that the system will use. In this case, variable primary flow will be selected for two reasons. The first reason is that most modern systems are selecting variable primary flow over primary/secondary systems because they prevent low delta T syndrome which will be an important consideration for Alternative 3. Second, variable primary flow systems tend to be more energy efficient and sometimes are not more expensive in first cost.

The selection of variable primary flow implies that both the pumps and air handling units should be equipped with variable frequency drives (VFD). Today, VFD's are not expensive relative to the savings they incur over the life of the equipment. They substantially increase efficiency and allow the system to operate with greater consistency.

The air handling unit that will be needed will in all likelihood resemble the rooftop unit from Alternative 1. This means that the air handling unit will have a supply and return fan, both equipped with VFD's and a 100% outdoor air dry-bulb economizer. The major difference is that the cooling coil would be supplied with either chilled water or glycol, another important consideration for Alternative 3, and not refrigerant. For heating, a boiler located in the rooftop penthouse will supply 180°F water to a heating coil located in the air handling unit.

Stemming from this proposed mechanical system redesign is the need to understand the feasibility. The roof is relatively empty and space is not a consideration. The building previously had an air handling unit inside of the rooftop penthouse and adding such a unit would be comparable to what was installed and then removed. The same is true of the pumps and boiler that would be required. In the case of adding a chiller, it would replace the rooftop units of Alternative 1. Where the feasibility needs to be studied is in the weight of the additional equipment and the structural capacity of the roof. This is where the first of two breadth analyses will take place.

Alternative 3 – Thermal Storage

The third mechanical alternative will be to study the benefits and drawbacks of adding thermal storage—specifically ice storage. This alternative will use the same principles as Alternative 2, however, the equipment sizing will be different. With ice storage, the system will operate at a larger temperature difference which will imply that the cooling coil will be sized differently in the air handling unit, the quantity of air supplied by the air handling unit can be reduced and the pumps will be smaller. Ice storage also allows the chiller to be reduced in size.

The biggest drawback to using an ice storage system is the size and weight requirement of the storage tanks. This is an extension of the breadth analysis mentioned as part of Alternative 2 regarding a structural study.

Shown below in Figure 2 is a rudimentary schematic of how an ice storage system might work. In Figure 3, a demonstration of peak shaving shows how ice storage will reduce the electric demand of the Park Place 1 during the cooling season. This is especially important and can be a major economic consideration because Park Place 1 is an office building. Office buildings generally have low load factors which implies lower energy efficiency and high peak demand. Ice storage is especially effective in increasing the load factor and saving money.

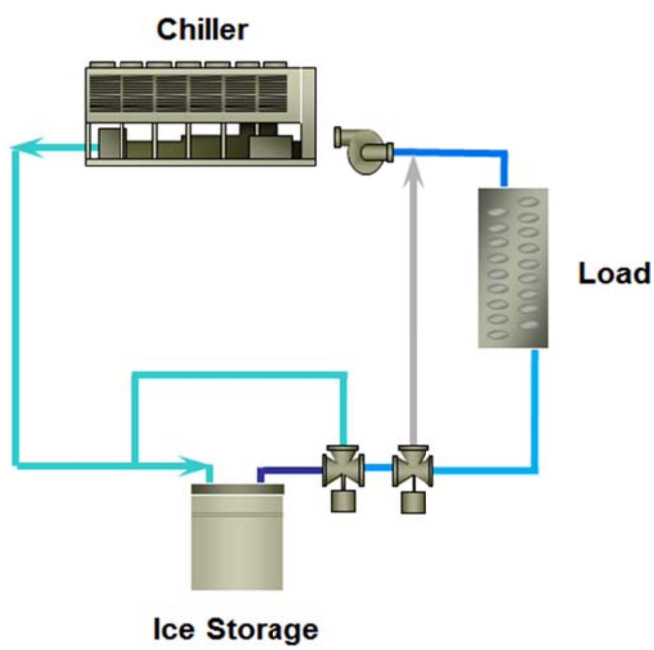


Figure 2 – Ice Storage Schematic

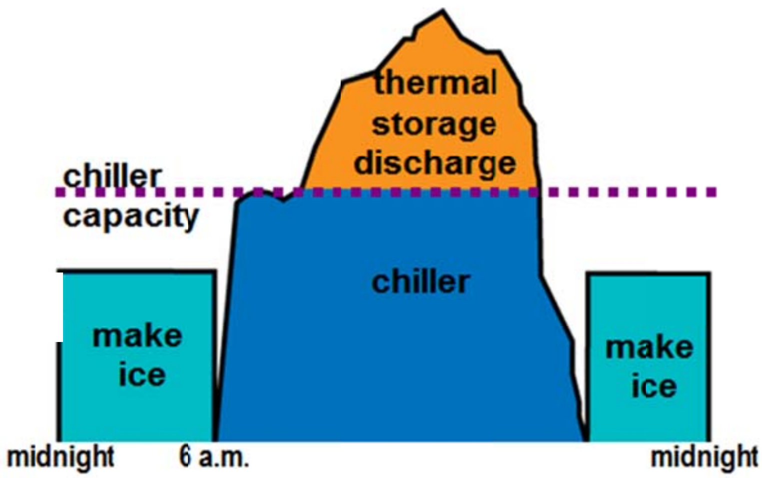


Figure 3 – Peak Shaving Strategy for Ice Storage System

Breadth Topics

Structural

The addition of a chiller and ice storage tanks adds a considerable amount of weight to the roof of Park Place 1. An investigation of the safety of this structure needs to be done to ensure that the equipment could be safely placed on the roof. Considering that the building structure was not designed to support such weight, a study will most likely show that the structure is inadequate. Once this study is complete, a structural redesign will be done to ensure safety with the systems installed. This new structure will then be analyzed to see if making such adjustments is economically viable.

Electrical

The three alternatives proposed will also require vastly different electrical capacities. Alternative 1 is how the building is designed today. Adding a chiller and removing the packaged RTU's, as proposed in Alternative 2, will change the electrical load on the building. Furthermore, adding thermal energy storage will reduce the overall demand that the building produces. This will reduce the electrical demand in comparison to Alternative 2, but it is unclear how similar or not the capacity requirement will relate to that of Alternative 1. The amount of money that could be saved in reducing the size and capacity of conduit and wiring might not be negligible and therefore will be the basis of a second breadth analysis.

Tools and Methods

Because this study is predominately cost based, initial cost of systems and equipment, construction, and energy consumption all need to be determined.

Equipment

All equipment cost will be determined from Trane and Calmac. Past work experience with both companies and an established relationship has made both companies reliable sources of equipment capacity, performance, and cost.

Energy Consumption

Energy consumption will be determined using Trane Trace 700. Similar to methods used in Technical Report 2, all building systems will be modeled to determine yearly energy consumption for Park Place 1 for all three alternatives. This information will then be used to calculate cost, again, similar to Technical Report 2.

Structural Study

STAAD will be used to model the existing and proposed structural systems for the roof. This will be used in conjunction with local codes to ensure a safely designed structural system.

Electrical Study

All electrical equipment capacities and sizes will be determined in accordance with the National Electric Code and local codes.

References

ASHRAE Handbook of Fundamentals 2005

CJL Engineering, Park Place Corporate Center One Renovation Mechanical, Electrical, and Plumbing Drawings and Specifications

DiCicco Development

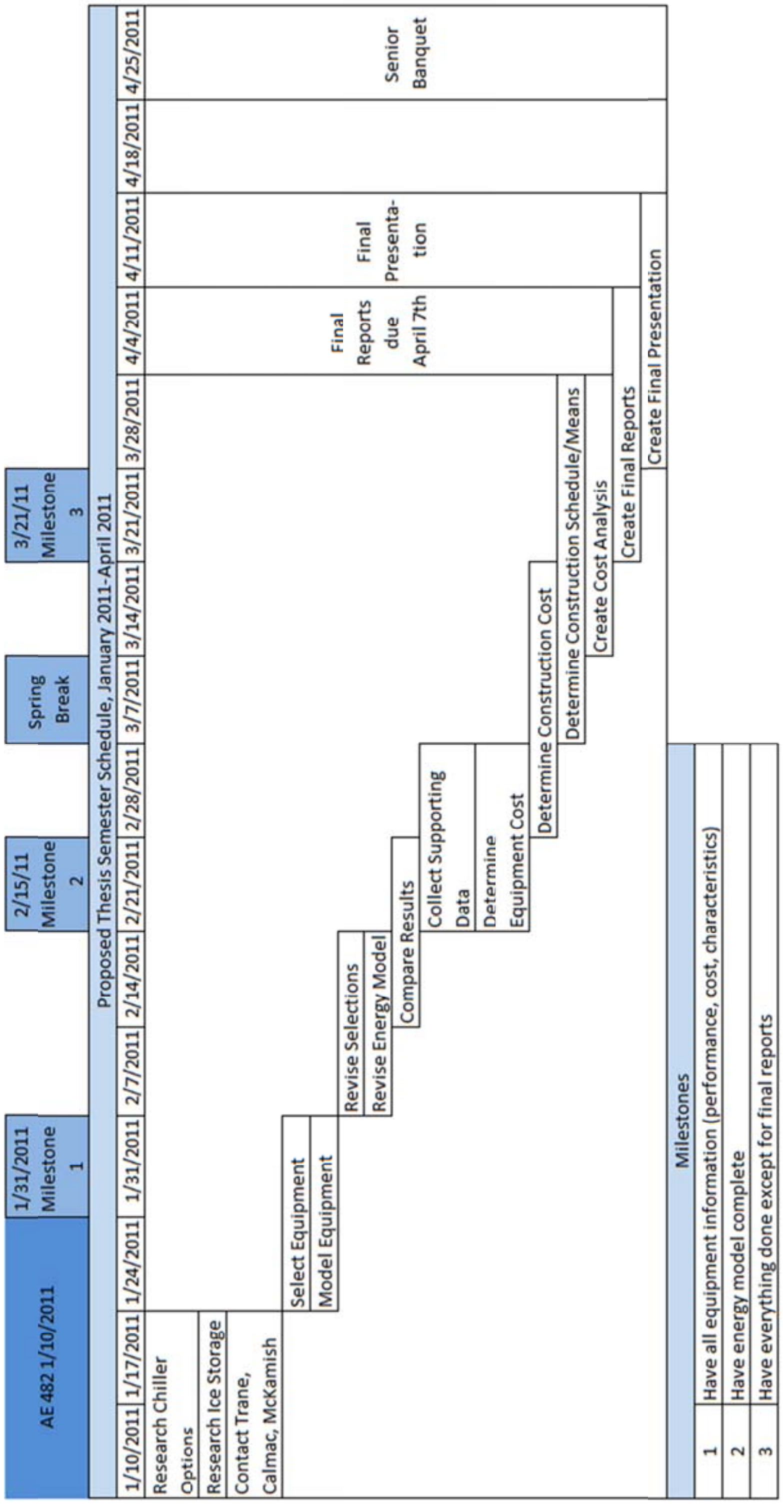
The National Electric Code

Past Thesis Technical Reports, e-Studio Archives, 2009-2010

WTW Architects, Park Place Corporate Center One Drawings

APPENDIX A

Work Plan



Appendix B

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